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DOE/NASA TECHNICAL MEMORANDUM

DOE/NASA TM-78223

DEVELOPMENT, TESTING, AND CERTIFICATION OF OWENS-ILLINOIS MODEL SEC-601 SOLAR ENERGY COLLECTOR SYSTEM – FINAL REPORT

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TABLE OF CONTENTS

	Page
SUMMARY	1
INTRODUCTION	3
Program Background and Goals	3
Purpose of This Product Development Contract	3
DESCRIPTION	4
Project Development Requirements and Criteria	4
General Description of the SEC-601 Solar Collector	5
Tubular Elements	5
Manifolding	8
Reflective Backing Screen	8
Mounting Hardware	10
Collector Performance Specification	10
Development Test Program	12
PROBLEMS ENCOUNTERED AND THEIR SOLUTIONS	12
Fabrication	12
Technical Performance	12
CONCLUSIONS AND RECOMMENDATIONS	15
GENERAL	15
APPENDIX	16
REFERENCES	17

LIST OF ILLUSTRATIONS

Figure	Title	Page
1.	Model SEC-601 solar energy collector systems	2
2.	Collector array	6
3.	Evacuated tubular solar collector	7
4.	Delivery tube with evacuated tubular collector	7
5.	Collector pair and manifold	7
6.	Collector array radiation interception	8
7.	Collector array reflective backing	9
8.	Efficiency as a function of operating conditions	11
9.	Test loop schematic model SEC-601 air-cooled collector	13
10.	Model SEC-601 collector efficiency	14

TECHNICAL MEMORANDUM

DEVELOPMENT, TESTING, AND CERTIFICATION OF OWENS-ILLINOIS MODEL SEC-601 SOLAR ENERGY COLLECTOR SYSTEM – FINAL REPORT

SUMMARY

The intended use for this report is to provide product development information as an aid to the solar heating and cooling systems manufacturing industry in their effort to determine the products adaptability for use in a specifically configured total solar heating and/or cooling system for residential and commercial applications.

This report will also serve as an aid to those who desire to remain abreast of the state-of-the-art of solar energy heating and cooling projects.

The Owens-Illinois Model SEC-601 Solar Energy Collector as developed under this contract had its beginning in the 1973 to 1974 time frame as a liquid-cooled collector. Over 7000 ft^2 of this type collector were installed at residential and commercial buildings in the U.S. Extensive development work on an air-cooled collector was underway during this time. In October of 1976, Owens-Illinois entered into a contract with the National Aeronautics and Space Administration (NASA)/Marshall Space Flight Center (MSFC) to upgrade the air-cooled collector and associated subsystems to satisfy certain additional requirements to assure that the product could be classified as a marketable product and suitable for public use.

The essential physical difference between the liquid type and air type is in the manifolding and air flow distribution; the all glass tubular elements are similar for both liquid and air systems. The thermal efficiencies of Owens-Illinois' all-liquid system and the all-air system is on the order of three percentage points in favor of the liquid system. This is a small penalty to pay for the elimination of field application problems experienced using a liquid in the collector loop.

The deliverable end item under this contract was four modules containing 334 ft^2 of collector area (Fig. 1). The hardware is modular in construction, one module consists of 72 tubular collectors with related manifolds and reflective

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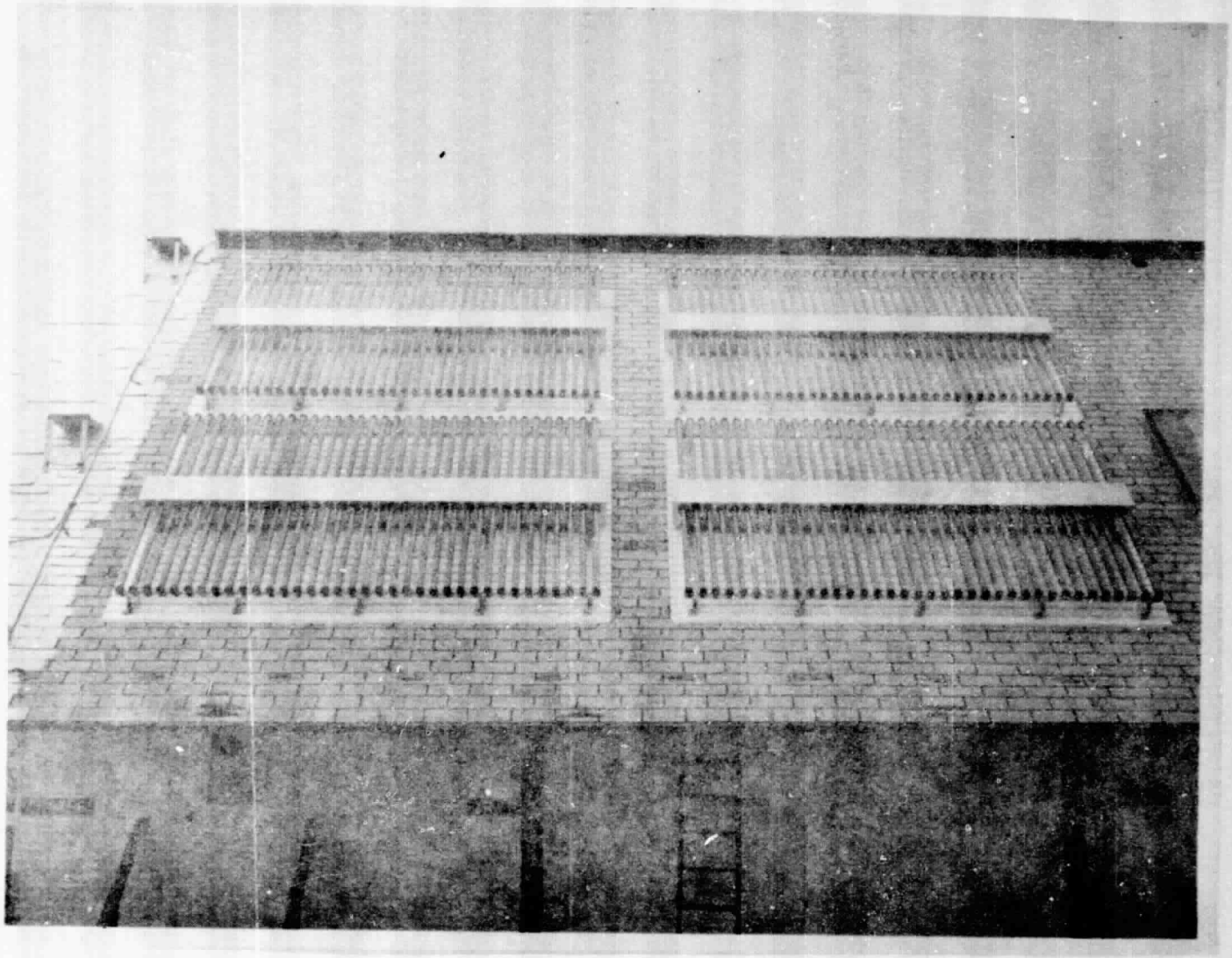

Figure 1. Model SEC-601 solar energy collector systems.

backing surface. These modules are high performance collectors capable of operating continuously at exit air temperatures up to 325°F. These high temperatures are necessary to efficiently drive solar air conditioning equipment.

At contract completion (over a 26-month period), Owens-Illinois obtained a certificate by the architectural and engineering firm, Smith, Hinchman and Grylls, acting as the independent certification agency, that the Model SEC-601 Solar Energy Collector System is a marketable subsystem for solar heating and combined heating and cooling systems for dwellings and commercial installations [1] (Appendix).

INTRODUCTION

Program Background and Goals

Prior to dealing with the specific aspects of the Owens-Illinois Solar Collector, a few background statements are pertinent. The problems of energy availability and increasing costs have led to a major national effort to develop alternate energy sources. One such source is the energy in solar radiation, which can be used for heating and cooling buildings, domestic hot water, and other applications. The National Energy Policy, as established in the Solar Heating and Cooling Demonstration Act of 1974 (PL93-409), is to provide for the demonstration within a 3-year period of the practical use of solar heating technology, and demonstration within a 5-year period of the practical use of combined heating and cooling technology. Responsibility for implementing the Demonstration Act was given to the Energy Research Development Administration (now the Department of Energy). NASA/MSFC manages a large part of this work.

Purpose of This Product Development Contract

The purpose of this contract was to provide funding to Owens-Illinois to do additional design, development, building, and testing on their existing model SEC-601 air-cooled collector. The objective was to demonstrate by analysis and tests that an all-glass evacuated tubular solar collector employing a selective coating on the air-carrying tube, together with the associated air manifolds, can perform continuously at high temperatures and transfer sufficient heat, directly or through heat exchangers and storage, to drive solar air conditioning equipment used to cool residential and commercial buildings. Specifically, the main thrust of the contractor's

effort was in developing a low-thermal-loss cost-effective manifolding and air-flow distribution systems for the evacuated tubular collector. (The basic air collector had already been demonstrated by analysis, test and experiment to operate efficiently.) Equalization of air flow distribution between collector tube elements also received a lot of design attention. These two development considerations were optimized since they are divergent in nature; low thermal loss (high efficiency) and low cost argue for small ducting and good flow distribution; whereas, low pumping power suggests large duct cross-sectional areas.

Contract performance period was from October 29, 1976, through August 31, 1978.

DESCRIPTION

Project Development Requirements and Criteria

During the development of the collector subsystem the contractor was required to:

1) Meet the applicable parts of the interim performance criteria for solar heating and cooling systems as stated in the subsystems performance specifications [2].

2) Provide test data/analysis to verify that hardware meets the subsystem performance specification [1].

3) Provide drawings and specifications in sufficient detail to define the configuration and to assure manufacturing repeatability [3].

4) Provide installation, operation, and maintenance manuals [4] and application information [5].

5) Provide program execution plans, design review data, periodic status reports and acceptance data packages.

6) Provide subsystem and/or component hardware certified by an independent test laboratory to meet nationally recognized standards and codes (such as American Society of Heating, Refrigeration and Air Conditioning Engineers; American Society for Mechanical Engineers; American Standards Institute and American Refrigeration Institute) [1].

General Description of the SEC-601 Solar Collector [5]

Each module is approximately 12-1/2 ft by 8-1/2 ft (106 ft^2). It weighs approximately 340 lb with collector tubes installed and 120 lb without the tubes installed. As a general statement, ten 72 tube modules will supply the heating and cooling requirements for a 2500 to 3500 ft^2 residence using an electric motor of approximately the same size as would be required for a conventional gas or oil heating system. The subsystem consists of (Figs. 1 and 2):

1) 72 glass tubular elements

2) 72 aluminum delivery tubes

3) Manifolding

4) Reflective backing screen

5) Mounting hardware.

Tubular Elements

The evacuated tubular, selectively coated elements are novel in most respects along side of their flat plate counterparts. Figures 3 through 7 present the tubular design concept.

The collector consists of two coaxial, round glass tubes closed at one end and open at the other. The inner tube (absorber tube) has selectively absorbing coating on its outer surface. The outer tube is the cover tube and is fused to the absorber tube. To minimize convection and conductive heat losses from the absorber tube and to maintain the integrity of the selective coating, the space between the inner and outer tube is evacuated.

An additional tube approximately 1-1/4 in. in diameter is inserted inside the "bottle-like" collector tube and the air to be heated enters the annulus between delivery and absorber tubes, and exits through the delivery tube (Fig. 4).

The collector tubes are organized in pairs providing a good workable collector module (Fig. 5). One delivery tube is assembled into each collector tube. Air enters the manifold which contains the inlets to the collector tube pairs and the air then flows through the collector pairs then reverses direction and flows through the delivery tubes and exits from the manifold.

Figure 2. Collector array.

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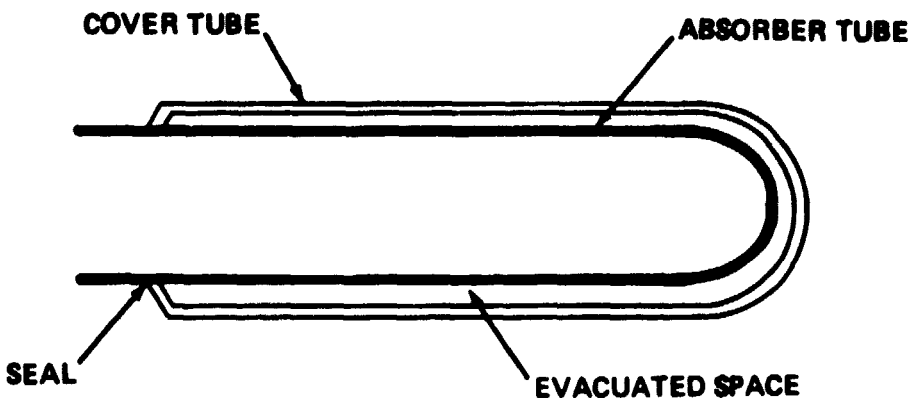

Figure 3. Evacuated tubular solar collector.

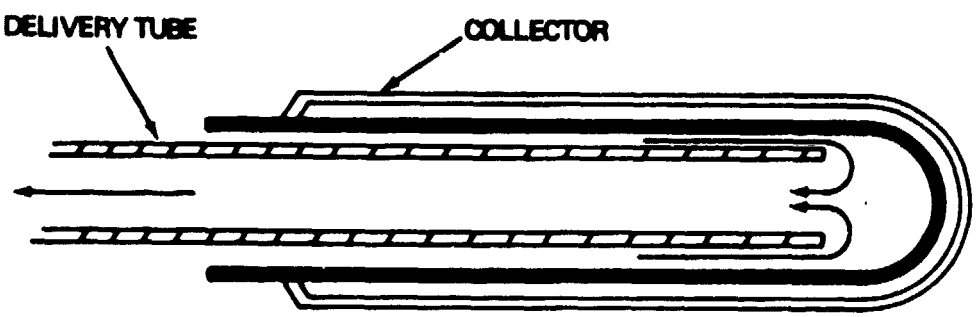

Figure 4. Delivery tube with evacuated tubular collector.

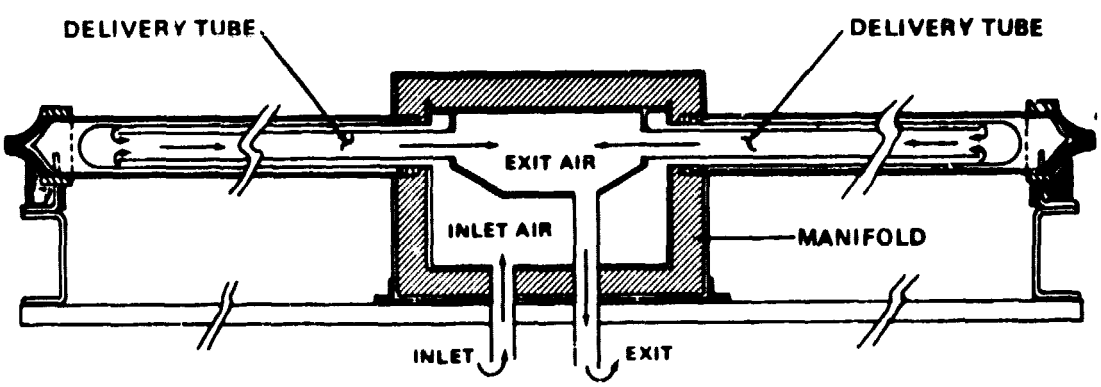

Figure 5. Collector pair and manifold.

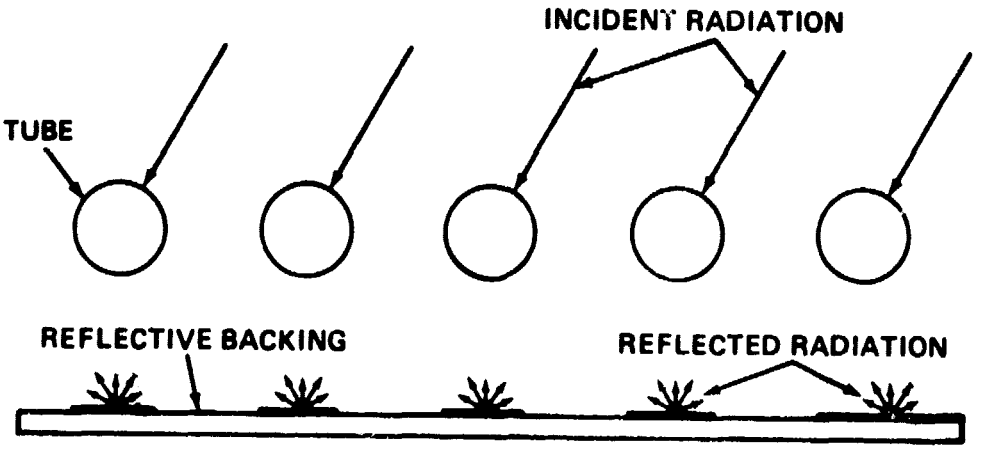

Figure 6. Collector array radiation interception.

To take advantage of their cylindrical shape, the tubes are positioned above a reflective backing surface as well as being positioned so that there is clear area between adjacent tubes (Fig. 6). The amount of radiation received by an individual collector will depend on the separation between tubes and the distance that the collector array is away from the backing surface. Trade-off studies were made to determine the optimum spacings. The Owens-Illinois SEC 601 air-cooled collector module subsystem hardware provides for 4-in. center to center spacing between collector tubes and approximately 6 in. of clearance between collectors and the backing reflective surface (Fig. 7).

Manifolding (Fig. 5)

These components are rectilinear in shape, fabricated from sheet metal, adequately insulated, sealed at the joints and sized so that the total air flow design rate is approximately 8 lb of air/hr-ft^2. Tests indicated that air loss through ducting and manifold seals was approximately 1 percent which was within specification.

Reflective Backing Screen

Owens-Illinois recommends that corrugated aluminum sheets painted with Alcoa bone white, or equivalent, be installed underneath the collector modules to act as a reflector. This surface has a reflectance of 78.57 percent. Figure 7 shows an alternate material, a white vinyl siding, used in the construction industry. This is considered equivalent and has a reflectance of 84 percent.

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Figure 7. Collector array reflective backing.
White vinyl siding used on MSFC Solar Demonstration Facility, Huntsville, Alabama.

Mounting Hardware [4]

This consists of aluminum framing, supports and hangers for mounting the collector modules.

Collector Performance Specification (Fig. 8)

The Owens-Illinois Solar Collector Model SEC-601 will collect a minimum of 1050 Btu/ft^2/day of energy at an inlet fluid temperature equal to or less than 160°F and an air flow rate equal to or greater than 2 SCFM/ft^2 under the following conditions:

Tilt Angle: Equal to latitude; Azimuth angle: 0°

Ambient Temperature: 30°F

Wind Velocity: 0–5000 ft/min

Date: March 21, September 21

Noon Solar Flux Normal to Collector Surface: 2330 Btu/ft^2 Day

Longitude: Any; Latitude: Any

Also, the solar collector will collect a minimum of 900 Btu/ft^2/day of energy at an inlet fluid temperature equal to or less than 220°F and an air flow rate equal to or greater than 2 SCFM/ft^2 under the following conditions:

Tilt Angle: Equal to latitude; Azimuth angle: 0°

Ambient Temperature: 50°F

Wind Velocity: 0–5000 ft/min

Date: March 21, September 21

Noon Solar Flux Normal to Collector Surface: 2330 Btu/ft^2/Day

Longitude: Any; Latitude: Any.

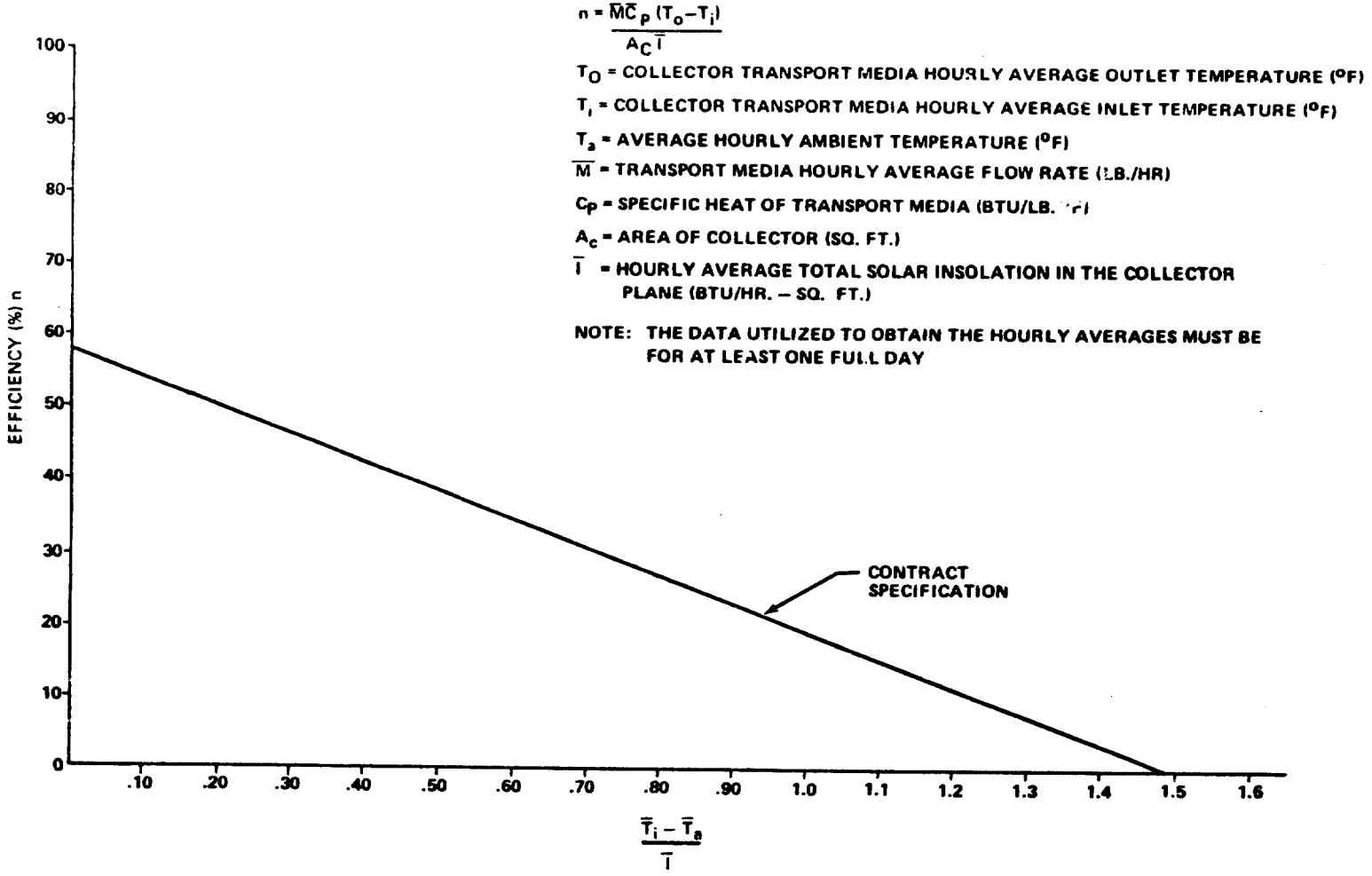

Figure 8. Efficiency as a function of operating conditions, performance must be above line.

Development Test Program

On March 15, 1977, Owens-Illinois entered into a contract with Smith, Hinchman and Gryllis Associates, Inc. (SH&G) of Detroit, Michigan, to perform the professional services necessary to assure that the Model SEC-601 collector module subsystem met national standards and codes. This work was accomplished at the Owens-Illinois Development Center in Toledo where SH&G established residency to perform this task.

The main thrust of this contractor's test effort was in testing and evaluating the collector subsystem in accordance with the interim performance criteria for solar heating and combined heating and cooling systems. The results of this effort is reflected in the qualification test and analysis report — solar collectors [1]. Figures 9 and 10 present the configuration of the test hardware and the collector efficiency resulting from the tests.

PROBLEMS ENCOUNTERED AND THEIR SOLUTIONS [6, 8, 9]

Fabrication

Most problems encountered were cost related and had to do with sheet metal parts, plastics and rubber products, and insulation and sealant materials, all separate and apart from the glass tube assemblies. These mechanical design changes required no change in the SEC-601 subsystem performance specification and by themselves were quite insignificant, but accumulatively they led to end item delivery delays and an extension of the contract performance period.

The solution to these problems was accomplished, in part, by obtaining production design and build expertise outside of Owens, Illinois. Cost savings will be fully realized with volume production.

Technical Performance

The manifold assembly, initially, was inadequate; severe air leakage from the manifold during test was close to 10 percent. The principal cause was gaps in the "slab type" insulation and the use of inadequate sealant material used for caulking and sealing joints.

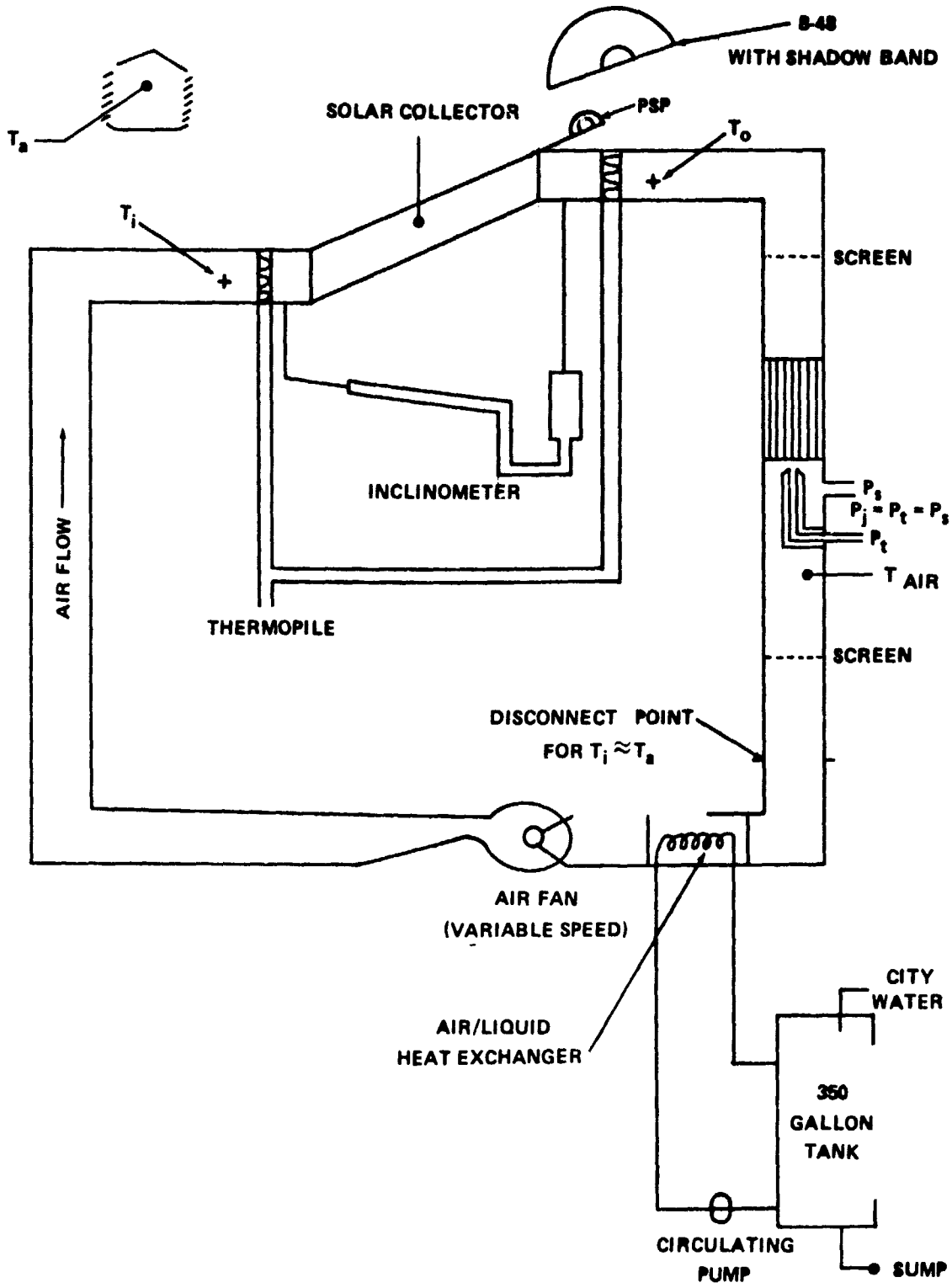

Figure 9. Test loop schematic model SEC-601 air-cooled collector.

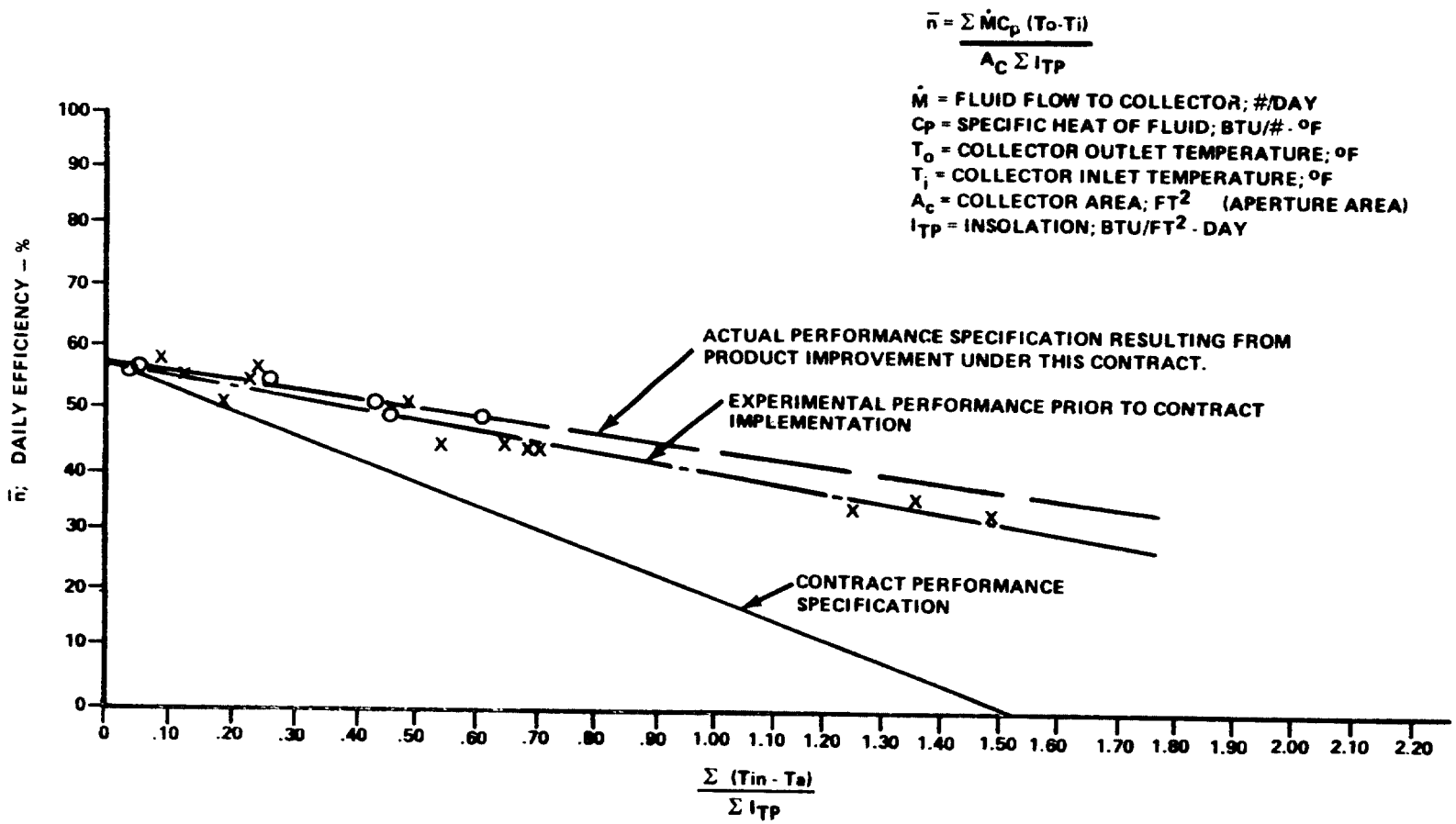

Figure 10. Model SEC-601 collector efficiency.

The solution to these problems was accomplished by substituting "foam-in-place" insulation and using a high temperature silicone sealant, catalytically activated. Air leakage was reduced to acceptable levels (1 percent).

CONCLUSIONS AND RECOMMENDATIONS [1, 7]

The Owens-Illinois Model SEC-601 solar energy collector (part number SK-5075) under this contract completed the test procedures of the Interim Performance Criteria (IPC) for Solar Heating and Combined Heating/Cooling Systems and Dwellings dated January 1, 1975, and is qualified, certified, and classified as a high performance, high temperature, air cooled collector available for commercial applications.

The collector operates with excellent efficiency at temperatures sufficiently high to drive solar air conditioning units, and shows good performance under diffuse light and low insolation conditions. Collector efficiency is insensitive to operating temperature, ambient temperature, and wind speed; the instantaneous efficiency is greater at the beginning and end of a day rather than at solar noon.

Because the cost to fabricate the prototype air manifold for the collectors turned out to be excessively high, it is recommended that a study be made to determine to what extent these costs can be reduced through the use of production type tooling, assuming a potential mass market.

It is recommended that a manufacturer of heating and cooling systems familiar with fabricating low cost sheet metal ducting and air flow mechanical and electrical systems team up with Owens-Illinois, and collectively extend their efforts to produce a low cost solar energy collector and manifold system and market the product on a large scale for installation in residential and commercial dwellings. One of the solar systems in operation at the NASA/MSFC Solar Demonstration Facility at Huntsville, Alabama, is the Owens-Illinois Model SEC-601. The Solar Demonstration Facility is open to the public.

GENERAL

The reference documents indicated by [ ] throughout the text are extensions of this final report and are recommended reading to provide a more detailed understanding of each hardware item developed under this contract. They may be obtained through DOE, Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830 or purchased from National Technical Information Service, Springfield, Virginia 22151.

APPENDIX

Certification Test Report

The Owens-Illinois, Inc., SUNPAK™ Model SEC 601 air cooled collector has been certified it meets national standards and codes as defined by the Subsystem Performance Specification and Verification Plan of contract NAS8-32259. The design, fabrication, installation and verification test and analysis of the Model SEC-601 collector were accomplished under contract NAS8-32259, dated October 28, 1976. The Architectural and Engineering firm , Smith, Hinchman and Grylls, Detroit, Michigan, acted in the capacity of the independent certification agency.

The SUNPAK™ Model SEC-601 collector was tested and evaluated to the applicable sections of the Interim Performance Criteria for Solar Heating and Combined Heating and Cooling Systems and Dwellings prepared for the U. S. Department of Housing and Urban Development by the National Bureau of Standards, dated January 1, 1975. The Model SEC-601 collector successfully completed all requirements and criterion of the Verification Test Program as evidenced by the documentation which follows.[1]

The SUNPAK™ Model SEC-601 air cooled collector is a marketable subsystem for solar heating and combined heating and cooling systems for dwellings and commercial installation.

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3. Preliminary Design Package for "Sunair" SEC-601 Solar Collector. DOE/NASA CR-150875, Owens-Illinois, Toledo, Ohio, Contract NAS8-32259, January 1979.

4. Installation Package for SunPak™ Solar Collectors. DOE/NASA CR-150802, Owens-Illinois, Toledo, Ohio, Contract NAS8-32259, September 1978.

5. Design Data Brochure for the Owens-Illinois SunPak™ Air-Cooled Solar Collector. DOE/NASA CR-150868, Owens-Illinois, Toledo, Ohio, Contract NAS8-32259, December 1978.

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8. Development of Prototype Air/Liquid Solar Collector Subsystem (Quarterly Report). DOE/NASA CR-150627, Owens-Illinois, Toledo, Ohio, Contract NAS8-32259, January 1978.

9. Development of Prototype Air/Liquid Solar Collector Subsystem (Sixth Quarterly Report). DOE/NASA CR-150703, Owens-Illinois, Toledo, Ohio, Contract NAS8-32259, May 1978.

APPROVAL

DEVELOPMENT, TESTING, AND CERTIFICATION OF OWENS-ILLINOIS MODEL SEC-601 SOLAR ENERGY COLLECTOR SYSTEM – FINAL REPORT

By John C. Parker

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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